Technical Report No. 190

# SUPPLEMENTAL REPORT ON PRIMARY PRODUCTIVITY AND ABIOTIC STUDIES AT THE DICKINSON SITE: 1970 SEASON

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ABSTRACT

This supplementary report to Technical Report 116 (Risser, 1972) develops additional aspects of plant productivity on the Dickinson Site during the 1970 season and describes quantitatively the energetics of the ecosystem on the grazed and ungrazed treatments at this site. Standing crop production was determined on grazed and ungrazed treatments on the basis of community peak standing crop, species peak standing crop, and the sum of positive growth increments. On the grazed treatment the species peak and the positive growth increment production estimates were both greater than the production estimate obtained from the community peak data. In this case, the species peak estimate was 19.4% greater than the community peak estimate, while the positive increment estimate was 44.4% greater than the community peak estimate. On the ungrazed treatment the estimate based on species peaks was 10.5% greater, and the positive growth increment estimate 27.2% greater than the community peak production estimate. On the basis of the variability in the production data, the positive growth increment method of estimating production did not seem to be valid. There did seem to be considerable justification for the use of species peak standing crops for the estimate of total community production.

Rates of above- and belowground production were also evaluated, with maximum aboveground production rates being obtained during the third week in June under both grazing treatments. Major belowground production took place at approximately the same time on both treatments as did major aboveground production.

Energy budgets for both treatments were developed using plant production data, precipitation and soil water values, soil heat flux data, and net radiation values. On a percentage basis, the grazed treatment net energy utilized was plant production, 0.79%; evapotranspiration, 57.57%; soil heat flux, 0.14%; and sensible heat, 41.50%. On the ungrazed treatment equivalent values were plant production, 1.04%; evapotranspiration, 50.77%; soil heat flux, 0.42%; and sensible heat, 47.77%. In the early part of the season evapotranspiration demands on the grazed treatment were so heavy that part of the energy used in the phenomenon was taken from the ambient air. On the ungrazed treatment there was no indication that advected heat was used in the energetics of the system.

# INTRODUCTION

This supplementary report to Technical Report No. 116 "Primary Productivity and Abiotic Studies at the Dickinson Site, 1970 Season," (Whitman, 1971) has been prepared to develop some additional aspects of the plant productivity pattern on the site during the 1970 season and to attempt to describe quantitatively the energetics of the ecosystem under the ungrazed and grazed treatments during the 1970 season. The increments of plant production and loss on both treatments have been calculated from basic data and the positive increments of standing crop production have been assembled and summed; the results of the three systems of determining total plant production, i.e., peak community biomass, peak species biomass, and the sum of positive growth increments by species have been contrasted for the two grazing treatments on the site.

Water balance data for both the ungrazed and grazed treatments are presented for the 155-day observation period in 1970. The soil heat balance data are calculated from soil temperatures and from periodic soil water values throughout the season. The final summation of site data is presented in the form of energy budgets of the two treatments calculated from plant production, seasonal precipitation, soil water changes, soil heat changes, and energy exchanges based on net radiation and caloric values (gains and losses of heat through soil-atmosphere interactions). Finally, a brief consideration of the validity of the energetics interpretation applied to the 1970 data from the Dickinson Site is included.

## SEASONAL STANDING CROP PRODUCTION

Basic data on primary production on the ungrazed and grazed treatments at the Dickinson Site in 1970 were given in Whitman (1971). These data are included (Appendix Tables 1 and 2) in the present report for purposes of reference, and all data on production presented in this report have been derived from those two tables' basic material.

Tables 1 and 2 give the increments of production and loss of standing crop occurring on the ungrazed and grazed treatments at the different dates of clipping throughout the 1970 season. The data were treated as though the gain and loss increments are valid, even though the calculations of error as provided by the Grassland Biome statistical laboratory indicate that such is frequently not the case. A comparison of the yield data with the phenological observations made on the site indicate that grass production, with some exceptions, was complete on both treatments by August 4. On the ungrazed treatment *Agropyron smithii* made some slight additional growth of fruiting stalks, as did *Bouteloua gracilis*, after this date; and *Calamovilfa longifolia*, with its late growth habit, made additional production of both leaves and stalks with maximum standing crop of this species being reached about mid-September. On the grazed treatment both *Agropyron smithii* and *Bouteloua gracilis* made some production after August 4, again primarily in the form of increased growth of fruiting stalks.

The major source of the relatively large increments of standing crop production late in the season on both sites, however, is in the development of late perennial forbs. On the ungrazed treatment the principal forb

Table 1. Increments of production and loss (negative values) of standing crop on the ungrazed treatment (1) at the Dickinson Site, 1970 season, in g/m$^2$.

| Species | Increments | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | to May 25 | May 26 to June 10 | June 11 to June 24 | June 25 to July 8 | July 9 to July 22 | July 23 to Aug. 4 | Aug. 5 to Aug. 18 | Aug. 19 to Sept. 17 | Sept. 18 to Oct. 17 |
| | | | | *Grasses* | | | | | |
| *Agropyron smithii* | 4.0 | 3.4 | 19.1 | -2.6 | +5.1 | -1.8 | +6.6 | +0.8 | -21.7 |
| *Bouteloua gracilis* | 1.2 | 3.6 | 5.6 | 9.0 | -0.5 | -5.5 | +8.5 | +0.9 | -4.8 |
| *Calamovilfa longifolia* | -- | 3.3 | 4.5 | 1.0 | 1.1 | -- | 6.7 | 13.4 | -10.0 |
| *Carex eleocharis* | 1.7 | 5.8 | 0.0 | 3.8 | -2.9 | +3.8 | -1.9 | -1.2 | +7.3 |
| *Stipa comata* | 26.2 | 7.6 | 15.8 | 27.8 | 23.4 | 17.5 | -13.2 | +0.4 | -1.8 |
| Miscellaneous grasses | -- | -- | 5.8 | -2.7 | -2.8 | +0.1 | +2.9 | +1.1 | +0.8 |
| | | | | *Forbs* | | | | | |
| *Artemisia ludoviciana* | 2.6 | 9.3 | 6.8 | 1.2 | 17.8 | -1.4 | +6.3 | +40.4 | -30.1 |
| All other forbs | 1.5 | 3.0 | 23.5 | 7.1 | -24.2 | +19.2 | -18.8 | +12.2 | -17.1 |
| COMMUNITY INCREMENTS | 37.2 | 36.0 | 81.7 | 44.0 | 24.0 | 22.0 | 7.0 | 68.0 | -77.4 |

Table 2. Increments of production and loss of standing crop on the grazed treatment (4) at the Dickinson Site, 1970 season, in $g/m^2$.

| Species | Increments | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | to May 25 | May 26 to June 10 | June 11 to June 24 | June 25 to July 8 | July 9 to July 22 | July 23 to Aug. 4 | Aug. 5 to Aug. 18 | Aug. 19 to Sept. 17 | Sept. 18 to Oct. 17 |
| | | | | *Grasses* | | | | | |
| *Agropyron smithii* | -- | 5.5 | 0.7 | 4.4 | 1.1 | -3.8 | +11.9 | -3.5 | -5.2 |
| *Bouteloua gracilis* | 4.2 | 14.1 | 23.7 | -4.2 | +12.8 | -4.5 | +13.8 | -3.9 | +3.9 |
| *Calamagrostis montanensis* | 21.5 | -2.4 | +4.3 | +3.2 | +0.5 | -7.2 | -4.6 | +5.3 | +1.7 |
| *Carex eleocharis* | 4.6 | 2.2 | 10.1 | -3.2 | +0.1 | -2.8 | +0.5 | -3.4 | -0.6 |
| *Koeleria cristata* | 5.5 | 6.8 | -5.9 | +11.6 | -4.7 | +5.2 | -1.7 | -6.5 | +5.6 |
| *Stipa comata* | 8.3 | 15.7 | 6.1 | 4.9 | 7.1 | 14.0 | -11.1 | +2.9 | -1.0 |
| Miscellaneous grasses | -- | 1.5 | -0.6 | -0.8 | +1.0 | -0.9 | +0.2 | -0.2 | -- |
| | | | | *Forbs* | | | | | |
| *Artemisia ludoviciana* | -- | -- | -- | 3.0 | -1.4 | +1.8 | +0.8 | +1.0 | -1.0 |
| All other forbs | 4.3 | 8.2 | 10.3 | 3.8 | 1.5 | -2.8 | -1.8 | +22.0 | -22.4 |
| COMMUNITY INCREMENTS | 48.4 | 51.6 | 48.7 | 22.7 | 18.0 | -1.0 | +8.0 | +13.5 | -23.2 |

involved in late biomass production was *Artemisia ludoviciana* (Table 1), although some other late forbs also contributed, notably *Liatris punctata*. On the grazed treatment *Artemisia ludoviciana* was of little importance and most of the late forb production was made by such perennial species as *Chrysopsis villosa*, *Liatris punctata*, *Lygodesmia juncea*, and *Artemisia frigida*. On both the ungrazed and grazed treatments the principal contribution to late growth was thus made by the perennial forbs as shown by the data of Table 1, where *Artemisia ludoviciana* and other perennial forbs showed a positive growth increment of 52.6 $g/m^2$ for the September 17 clipping and by Table 2 where the other perennial forbs and *A. ludoviciana* showed a positive increment of 23.0 $g/m^2$ for the same clipping.

The largest increments of production under both treatments were made during the early part of the season as would be expected. The largest aboveground production increment on the ungrazed treatment occurred during the period between June 11 and June 24. The increment on the ungrazed treatment for this period was 81.7 $g/m^2$. On the grazed treatment a production increment of 51.6 $g/m^2$ occurred during the May 26 to June 10 period, the greatest individual production increment of the season on this treatment. The data of Table 2 indicate that the bulk of the standing crop production on the grazed treatment was made somewhat earlier than on the ungrazed treatment (Table 1).

Significant losses of standing crop material began to appear after July 22 on both treatments. Really serious losses of plant material did not become apparent, however, until after the September 17 clipping. The last clipping of the season, made about the middle of October, showed that substantial losses of standing crop material had occurred under both treatments between mid-September and the time of the last clipping.

The overall production of aboveground standing crop under the two treatments at the Dickinson Site can be characterized as follows. Growth began in late April under both treatments, with the bulk of the standing crop being produced prior to June 24 and with grass production being largely completed by August 4. Grass production began somewhat earlier on the grazed treatment than on the ungrazed treatment. Late season production on both treatments largely resulted from the development of late perennial forbs. Production increments for the first two periods of growth, as determined from the quadrat clippings, were greater on the grazed treatment than on the ungrazed treatment. Later growth increments were generally greater on the ungrazed treatment than on the grazed treatment.

Losses of standing crop material began to appear as early as mid-July, but serious losses of standing crop material (current season's production) did not take place until after mid-September.

## COMPARISON OF STANDING CROP PRODUCTION

Table 3 presents the summation of positive increments of standing crop production on the ungrazed treatment as derived from the data of Table 1. The same summation for standing crop production on the grazed treatment is given in Table 4 with the increments derived from the data of Table 2. The sum of the positive production increments by species on the ungrazed treatment was found to be 407.0 $g/m^2$, while the sum of the positive increments by species on the grazed treatment was 303.2 $g/m^2$.

Table 3. Summation of positive increments of production of standing crop on the ungrazed treatment (1) at the Dickinson Site, 1970 season, in g/m$^2$.

| Species | Positive Increments | | | | | | | Sum of Positive Increments |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| | | | *Grasses* | | | | | |
| *Agropyron smithii* | 4.0 | 3.4 | 19.1 | 5.1 | 6.6 | 0.8 | -- | 39.0 |
| *Bouteloua gracilis* | 1.2 | 3.6 | 5.6 | 9.0 | 6.5 | 8.5 | 0.9 | 35.3 |
| *Calamovilfa longifolia* | 3.3 | 4.5 | 1.0 | 1.1 | 6.7 | 13.4 | -- | 30.0 |
| *Carex eleocharis* | 1.7 | 5.8 | 3.8 | 3.8 | 7.3 | -- | -- | 22.4 |
| *Stipa comata* | 26.2 | 7.6 | 15.8 | 27.8 | 23.4 | 17.5 | 0.4 | 118.7 |
| Miscellaneous grasses | 5.8 | 0.1 | 2.9 | 1.1 | 0.8 | -- | -- | 10.7 |
| | | | *Forbs* | | | | | |
| *Artemisia ludoviciana* | 2.6 | 9.3 | 6.8 | 1.2 | 17.8 | 6.3 | 40.4 | 84.4 |
| All other forbs | 1.5 | 3.0 | 23.5 | 7.1 | 19.2 | 12.2 | -- | 66.5 |
| TOTALS | | | | | | | | 407.0 |

Table 4. Summation of positive increments of production of standing crop on the grazed treatment (4) at the Dickinson Site, 1970 season, in $g/m^2$.

| Species | Positive Increments | | | | | | | Sum of Positive Increments |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| | | | *Grasses* | | | | | |
| *Agropyron smithii* | 5.5 | 0.7 | 4.4 | 1.1 | 11.9 | -- | -- | 23.6 |
| *Bouteloua gracilis* | 4.2 | 14.1 | 23.7 | 12.8 | 13.8 | 3.9 | -- | 72.5 |
| *Calamagrostis montanensis* | 21.5 | 4.3 | 3.2 | 0.5 | 5.3 | 1.7 | -- | 36.5 |
| *Carex eleocharis* | 4.6 | 2.2 | 10.1 | 0.1 | 0.5 | -- | -- | 17.5 |
| *Koeleria cristata* | 5.5 | 6.8 | 11.6 | 5.2 | 5.6 | -- | -- | 34.7 |
| *Stipa comata* | 8.3 | 15.7 | 6.1 | 4.9 | 7.1 | 14.0 | 2.9 | 59.0 |
| Miscellaneous grasses | 1.5 | 1.0 | 0.2 | -- | -- | -- | -- | 2.7 |
| | | | *Forbes* | | | | | |
| *Artemisia ludoviciana* | 3.0 | 1.8 | 0.8 | 1.0 | -- | -- | -- | 6.6 |
| All other forbs | 4.3 | 8.2 | 10.3 | 3.8 | 1.5 | 22.0 | -- | 50.1 |
| TOTAL | | | | | | | | 303.2 |

The data of Tables 3 and 4 illustrate some significant differences in the species composition of the standing crop production on the ungrazed and grazed treatments. *Stipa comata* showed a positive growth increment total of 118.7 g/m$^2$ on the ungrazed treatment and only 59.0 g/m$^2$ on the grazed treatment. In contrast, *Bouteloua gracilis* showed a positive growth increment total of 72.5 g/m$^2$ on the grazed treatment and only 35.3 g/m$^2$ on the ungrazed treatment. *Calamagrostis montanensis* and *Koeleria cristata* made significant contributions to standing crop only on the grazed treatment, while *Calamovilfa* was important only on the ungrazed treatment. *Artemisia ludoviciana* was an important contributor to yield only on the ungrazed treatment, although other forbs contributed substantially on both treatments. Total forb production, calculated on the basis of positive growth increments, was nearly twice as great on the ungrazed as on the grazed treatment, mainly because of the contribution of *A. ludoviciana*.

Table 5 compares total aboveground standing crop production on the two treatments as determined on the basis of community peak standing crops, species peak standing crops, and sum of the positive production increments. On the ungrazed treatment total standing crop production at community peak standing crop was 319.9 g/m$^2$; based on species peaks the total was 353.6 g/m$^2$, and on the basis of species positive growth increments the total was 407.0 g/m$^2$. Thus, on this treatment the estimate based on species peaks was 10.5% greater than the community peak estimate, while the estimate based on positive growth increments was 27.2% greater than the community peak estimate.

The community peak estimate on the grazed treatment was 209.0 g/m$^2$; the estimate from species peaks was 250.7 g/m$^2$, and the estimate from the

Table 5. Total net standing crop production (g/m²) on the ungrazed and grazed treatments at the Dickinson Site, 1970 season, as estimated from community peak standing crops, species peak standing crops, and sum of positive species yield increments.

| Species | Ungrazed (1) | | | Grazed (4) | | |
|---|---|---|---|---|---|---|
| | Community Peak Standing Crops | Species Peak Standing Crops | Sum of Positive Species Increments | Community Peak Standing Crops | Species Peak Standing Crops | Sum of Positive Species Increments |
| | | | *Grasses* | | | |
| *Agropyron smithii* | 34.6 | 34.6 | 39.0 | 16.3 | 19.8 | 23.6 |
| *Bouteloua gracilis* | 29.8 | 29.8 | 35.3 | 56.0 | 59.9 | 72.5 |
| *Calamagrostis montanensis* | -- | -- | -- | 20.6 | 27.1 | 36.5 |
| *Calamovilfa longifolia* | 30.0 | 30.0 | 30.0 | -- | -- | -- |
| *Carex eleocharis* | 9.1 | 12.2 | 22.4 | 8.1 | 16.9 | 17.5 |
| *Koeleria cristata* | -- | -- | -- | 10.3 | 18.5 | 34.7 |
| *Stipa comata* | 105.5 | 118.3 | 118.7 | 47.9 | 56.1 | 59.0 |
| Miscellaneous grasses | 4.4 | 5.8 | 10.7 | | 1.5 | 2.7 |
| | | | *Forbs* | | | |
| *Artemisia ludoviciana* | 83.0 | 83.0 | 84.4 | 5.2 | 5.2 | 6.6 |
| All other forbs | 23.5 | 39.9[a/] | 66.5 | 45.5 | 45.7[a/] | 50.1 |
| TOTALS | 319.9 | 353.6 | 407.0 | 209.9 | 250.7 | 303.2 |

a/ Sum of peak standing crop of each of the three classes of forbs.

positive growth increments was 303.2 g/m$^2$. The species peak estimate was 19.4% greater than the community peak in this case, while the positive increment estimate was 44.4% greater than the community peak estimate.

In view of the errors involved in the determination of production from periodic clippings as made in this study, there would seem to be little justification for the use of the positive growth increments as a basis for the estimate of total net standing crop production. However, the clipping data do show rather definitely that different species reach peak production at different times during the season. On this basis, there does seem to be considerable justification for using the species peak standing crops for the estimate of total community production. The fact that percentage increase in the estimate of total net standing crop production from species peaks rather than from the community peak was greater on the grazed treatment than on the ungrazed treatment may be a reflection of a tendency for the loss rate from vegetation to be greater on the grazed site than on the ungrazed site.

## PRODUCTIVITY RATES

Daily productivity rates have been calculated from the basic data, and the calculated rates for the ungrazed treatment are given in Table 6 while the rates for the grazed treatment are given in Table 7. The data are given as grams per meter squared per day (dry weight) of plant material. Approximate dates of beginning of growth for the different species are given to provide a base for the calculation of the production rate prior to the first clipping on May 25. Loss rates from standing crop are represented by negative values.

Table 6. Average daily productivity ($g/m^2$) and loss rates of species, groups, and total community on the ungrazed treatment (1) at the Dickinson Site, 1970 season.

| Species | Date of Beginning Growth[a/] | Rates of Production | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | to May 25 | May 26 to June 10 | June 11 to June 24 | June 25 to July 8 | July 9 to July 22 | July 23 to Aug. 4 | Aug. 5 to Aug. 18 | Aug. 19 to Sept. 17 | Sept. 18 to Oct. 17 |
| | | | | | *Grasses* | | | | | |
| *Agropyron smithii* | April 20 | 0.11 | 0.23 | 1.36 | -0.19 | +0.36 | -0.14 | +0.47 | +0.03 | -0.72 |
| *Bouteloua gracilis* | May 15 | 0.11 | 0.24 | 0.40 | 0.64 | 0.46 | -0.42 | +0.61 | 0.03 | -0.16 |
| *Calamovilfa longifolia* | May 20 | -- | 0.16 | 0.32 | 0.07 | 0.08 | 0.00 | 0.48 | 0.45 | -0.33 |
| *Carex eleocharis* | April 20 | 0.05 | 0.39 | 0.00 | 0.27 | -0.21 | +0.29 | -0.14 | -0.04 | +0.24 |
| *Stipa comata* | April 20 | 0.73 | 0.51 | 1.13 | 1.99 | 1.67 | 1.35 | -0.94 | +0.01 | -0.06 |
| Miscellaneous grasses | May 20 | -- | -- | 0.17 | -0.19 | -0.20 | +0.01 | +0.21 | +0.04 | +0.03 |
| | | | | | *Forbs* | | | | | |
| *Artemisia ludoviciana* | May 5 | 0.12 | 0.62 | 0.49 | 0.09 | 1.27 | -0.11 | +0.45 | +1.35 | -1.00 |
| All other forbs | May 5 | 0.07 | 0.20 | 1.68 | 0.51 | -1.73 | +1.48 | -1.34 | +0.41 | -0.57 |
| TOTAL COMMUNITY | April 20 | 1.03 | 2.40 | 5.84 | 3.14 | 1.71 | 1.69 | 0.50 | 2.27 | -2.58 |

a/ Approximate date.

Table 7. Average daily productivity ($g/m^2$) and loss rates of species, groups, and total community on the grazed treatment (4) at the Dickinson Site, 1970.

| Species | Date of Beginning Growth[a/] | to May 25 | May 26 to June 10 | June 11 to June 24 | June 25 to July 8 | July 9 to July 22 | July 23 to Aug. 4 | Aug. 5 to Aug. 18 | Aug. 19 to Sept. 17 | Sept. 18 to Oct. 17 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Rates of Production | | | | | | | | |
| *Grasses* | | | | | | | | | | |
| *Agropyron smithii* | April 20 | -- | 0.11 | 0.05 | 0.31 | 0.08 | -0.29 | +0.85 | -0.12 | -0.17 |
| *Bouteloua gracilis* | May 10 | 0.26 | 0.94 | 1.69 | -0.30 | +0.91 | -0.35 | +0.99 | -0.13 | +0.13 |
| *Calamagrostis montanensis* | April 20 | 0.60 | -0.16 | +0.31 | +0.23 | +0.04 | -0.55 | -0.33 | +0.18 | +0.06 |
| *Carex eleocharis* | April 20 | 0.13 | 0.15 | 0.72 | -0.23 | +0.01 | -0.22 | +0.04 | -0.11 | -0.02 |
| *Koeleria cristata* | April 20 | 0.15 | 0.45 | -0.42 | +0.83 | -0.34 | +0.40 | -0.12 | -0.22 | +0.19 |
| *Stipa comata* | April 20 | 0.23 | 1.05 | 0.44 | 0.35 | 0.51 | 1.08 | -0.79 | +0.10 | -0.03 |
| Miscellaneous grasses | May 15 | -- | 0.06 | -0.04 | -0.06 | +0.07 | -0.07 | +0.01 | -0.01 | -- |
| *Forbs* | | | | | | | | | | |
| *Artemisia ludoviciana* | May 5 | -- | -- | -- | 0.05 | -0.10 | +0.14 | +0.06 | +0.03 | -0.03 |
| All other forbs | May 5 | 0.20 | 0.55 | 0.74 | 0.27 | 0.11 | -0.22 | -0.13 | +0.73 | -0.75 |
| TOTAL COMMUNITY | April 20 | 1.34 | 3.44 | 3.48 | 1.62 | 1.29 | -0.08 | +0.57 | +0.45 | -0.77 |

[a/] Approximate date.

In interpreting the tables it should be remembered that the periods between clippings are not all of equal length. The first period to May 25 varies in length according to species from 6 days to 36 days. The last two periods are each 30 days in length. The periods between May 26 and August 4 are each 14 days in length or within a day, more or less, of the 14-day period.

The maximum rate of aboveground standing crop productivity on the ungrazed treatment occurred during the period June 11 to 24, with an average rate of 5.84 g/m$^2$/day for the 2-week period. The maximum productivity rate was achieved on the grazed treatment during the same 2-week period, with the rate recorded at 3.48 g/m$^2$/day. On the grazed treatment the production rate of the previous 2-week period (May 26 to June 10) of 3.44 g/m$^2$/day was very nearly equal to the maximum rate recorded for the following 2-week period. On the ungrazed site, however, the 2.40 g/m$^2$/day production for the May 25 to June 10 period was less than half the rate recorded during the period of maximum production.

The relatively high productivity rates on the total community basis continued on the ungrazed treatment until mid-September as shown by the data of Table 6. These rates were maintained at relatively high levels late into the season primarily because of the late production of *Calamovilfa longifolia* and the perennial forb components. During the last 30-day period from September 18 to October 17, the daily loss rate was very high (2.58 g/m$^2$/day) on this treatment. Positive community production rates also continued into the latter part of the season on the grazed treatment, although they were not as high for the most part as were the rates on the ungrazed treatment. No one species or group on either treatment showed positive production rates for all clipping periods.

Belowground biomass data are given in Tables 33 and 34 (Whitman, 1971). These data show that major belowground production took place at approximately the same time on both treatments as did major aboveground standing crop production. Data from the ungrazed treatment show positive belowground growth increments of 35.1 g/m$^2$ on the June 15 sampling date, 679.1 g/m$^2$ on June 25, 58.6 g/m$^2$ on July 10, and 160.4 g/m$^2$ on July 19. On the grazed treatment only one positive belowground production increment was recorded, an increment of 606.1 g/m$^2$ on the June 25 sampling date. It would appear that actual root production was substantially less on the grazed treatment than on the ungrazed treatment, even though the seasonal average belowground biomass on the grazed site was 2,519.1 g/m$^2$, 56% more than the 1,613.9 g/m$^2$ average of belowground biomass on the ungrazed treatment.

The productivity rates of the belowground biomass have not been included in the data given in Tables 6 and 7. However, if the productivity rates of belowground production were added in the major production periods in June, the productivity rates for these periods on both treatments would be greatly increased. On the ungrazed treatment the increment of production (679.1 g/m$^2$) would represent the growth for the period of June 11 to 24. For the 14-day period this represents a productivity rate of 48.5 g/m$^2$/day, vastly greater than any of the aboveground production rates. The growth increment for the period May 26 to July 11 could be considered the 35.1 g/m$^2$ increment, which represents a productivity rate of 2.34 g/m$^2$/day.

The positive increment of root growth recorded for the grazed treatment occurred between June 15 and June 25. This increment could therefore be assigned to the June 11 to June 24 period, and would represent a belowground biomass production rate of 43.29 $g/m^2$/day--many times that of any of the rates recorded for the aboveground standing crop.

Rates of aboveground standing crop production have been converted from grams per meter squared to calories per centimeter squared per day. The data derived from this conversion are given in Table 8. In this calculation only the positive increments of production have been used, and the components of production have been grouped into grasses and sedges, forbs, and community totals. The caloric value used in making this conversion was the average of the values for plant materials on the site during the 1969 season. This value was 4,440 cal/g. The data from which this factor was calculated are given in Appendix Tables 3 and 4 of this report.

As would be anticipated, the maximum daily rate of calorie production occurred during the June 11 to 24 period. Total community production on the ungrazed treatment averaged 2.46 $cal/cm^2$/day for this period and 1.76 $cal/cm^2$/day on the grazed treatment. The greatest rate of grass production occurred during the same period on both treatments. The caloric productivity values obtained in the 1970 season were not as high as some that were obtained on the site in other seasons for the aboveground standing crop. They were, however, greater than the maximum daily productivity rate of 1.47 $cal/cm^2$/day obtained from the ungrazed treatment in the 1969 season.

It seems reasonable to assume that higher rates of aboveground production would be revealed by more frequent sampling, possible by stepping up the sampling frequency to one sampling per week rather than one every 2 weeks. Very rapid growth periods do occur in June and early July, and these should

Table 8. Rates of aboveground production in cal/cm$^2$/day on the ungrazed and grazed treatments at the Dickinson Site, 1970 season.[a/]

| Treatment | Group | Rates of Production | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | to May 25 | May 26 to June 10 | June 11 to June 24 | June 25 to July 8 | July 9 to July 22 | July 23 to Aug. 4 | Aug. 5 to Aug. 18 | Aug. 19 to Sept. 17 | Sept. 18 to Oct. 17 |
| Ungrazed | All grasses and sedges | 0.44 | 0.68 | 1.50 | 1.32 | 1.14 | 0.73 | 0.79 | 0.25 | 0.12 |
| | All forbs | 0.01 | 0.36 | 0.96 | 0.27 | 0.56 | 0.66 | 0.20 | 0.78 | 0.00 |
| | Total community | 0.45 | 1.04 | 2.46 | 1.59 | 1.70 | 1.39 | 0.99 | 1.03 | 0.12 |
| Grazed | All grasses and sedges | 0.61 | 1.23 | 1.43 | 0.76 | 0.72 | 0.66 | 0.84 | 0.12 | 0.17 |
| | All forbs | 0.09 | 0.24 | 0.33 | 0.14 | 0.05 | 0.06 | 0.03 | 0.34 | 0.00 |
| | Total community | 0.70 | 1.47 | 1.76 | 0.90 | 0.77 | 0.72 | 0.87 | 0.46 | 0.17 |

a/ Calculated from positive increments of growth on the treatments as given in Tables 6 and 7. In calculation, 1 g dry wt = 4,440 cal.

be capable of adequate characterization, providing sampling is adequate. It seems consistent with reported data that at certain times, production rates of 5 to 10 cal/cm$^2$/day might be detectable (Moir, 1969).

## ENERGY RELATIONS

Energy budgets for the two treatments have been worked out for the 1970 season at the Dickinson Site using the formula

$$R_n = S + P + E + A$$

where $R_n$ = net radiation, S = soil heat flux, P = net plant production, E = evapotranspiration, and A = sensible heat or ambient air heat flux. All data have been converted to cal/m$^2$. On the site, direct measurements were made of net radiation and of plant production, within the limits of error. Soil heat flux was calculated from soil temperature and soil water changes over the observed periods. Evapotranspiration was calculated from precipitation measurements and soil water determinations. Ambient air energy flux was taken as the difference between $R_n$ and the sum of S, P, and E. Obviously, certain errors enter into broad-scale calculations such as these.

Water balance data for the ungrazed and grazed treatments are given in Tables 9 and 10. The final calculations given in these tables represent the energy utilized in evapotranspiration on the two treatments in the 1970 season. Slatyer (1967) gives the formula for the determination of evapotranspiration (E) by the water balance method as

$$E = P_r + U - 0 - D - \Delta W$$

Table 9. Water balance on the ungrazed treatment (1) at the Dickinson Site, 1970 season.

| Period | No. of Days in Period | Precipitation Received (mm) | Water in Soil at Start of Period (mm) | Water in Soil at End of Period (mm) | Water Balance (mm) | Water Lost ($g/m^2$) | Calories[a/] Used Per $m^2$ (×1000) |
|---|---|---|---|---|---|---|---|
| May 16 to May 25 | 10 | 16.25 | 237.10 | 248.50 | -4.85 | 4,850 | 2,876 |
| May 26 to June 10 | 16 | 27.17 | 248.50 | 241.00 | -34.67 | 34,670 | 20,559 |
| June 11 to June 24 | 14 | 50.28 | 241.00 | 236.10 | -55.18 | 55,180 | 32,722 |
| June 25 to July 8 | 14 | 2.54 | 236.10 | 178.40 | -60.24 | 60,240 | 35,722 |
| July 9 to July 22 | 14 | 27.44 | 178.40 | 111.00 | -94.84 | 94,840 | 56,240 |
| July 23 to August 4 | 13 | 86.10 | 111.00 | 156.90 | -40.20 | 40,200 | 23,839 |
| August 5 to August 18 | 14 | 5.84 | 156.90 | 94.00 | -68.74 | 68,740 | 40,763 |
| August 19 to September 17 | 30 | 23.62 | 94.00 | 81.70 | -35.92 | 35,920 | 21.301 |
| September 18 to October 17 | 30 | 27.17 | 81.70 | 87.60 | -21.27 | 21,270 | 12,613 |
| TOTALS | 155 | 266.41 | -- | -- | -415.91 | 415,910 | 246,635 |

a/ ($g/m^2$ × 593).

Table 10. Water balance on the grazed treatment (4) at the Dickinson Site, 1970 season.

| Period | No. of Days in Period | Precipitation Received (mm) | Water in Soil at Start of Period (mm) | Water in Soil at End of Period (mm) | Water Balance (mm) | Water Lost ($g/m^2$) | Calories[a] Used Per $m^2$) (×1000) |
|---|---|---|---|---|---|---|---|
| May 16 to May 25 | 10 | 16.25 | 248.10 | 202.10 | -62.25 | 62,250 | 36,914 |
| May 26 to June 10 | 16 | 27.17 | 202.10 | 218.20 | -11.07 | 11,070 | 6,565 |
| June 11 to June 24 | 14 | 50.28 | 218.20 | 152.80 | -115.68 | 115,680 | 68,598 |
| June 25 to July 8 | 14 | 2.54 | 152.80 | 120.20 | -35.14 | 35,140 | 20,838 |
| July 9 to July 22 | 14 | 27.44 | 120.20 | 89.90 | -57.74 | 57,740 | 34,240 |
| July 23 to August 4 | 13 | 86.10 | 89.90 | 124.30 | -51.70 | 51,700 | 30,658 |
| August 5 to August 18 | 14 | 5.84 | 124.30 | 98.40 | -31.74 | 31,740 | 18,822 |
| August 19 to September 17 | 30 | 23.62 | 98.40 | 82.40 | -39.62 | 39,620 | 23,495 |
| September 18 to October 17 | 30 | 27.17 | 82.40 | 87.30 | -22.27 | 22,270 | 13,206 |
| TOTALS | 155 | 266.41 | -- | -- | -427.21 | 427,210 | 253,336 |

a/ ($g/m^2 \times 593$).

where $P_r$ = precipitation, U = unsaturated flow into the root zone, O = surface runoff, D = drainage through percolation, and $\Delta W$ = the change in water content of the soil over the period of observation. In these calculations precipitation was measured and the change in soil water content was determined. The U, O, and D determinations were considered negligible on this site. Volumetric soil water content under the two treatments was calculated from percent soil water and bulk density data. Values for these calculations to a depth of 120 cm are given in Table 6 (Whitman, 1971).

Precipitation on the site totaled 266.41 mm during the 155-day observation period. Periods of major precipitation occurred during June 11 to 24 and July 23 to August 4. A total of 415.91 mm/cm$^2$ of water was lost by evapotranspiration from the ungrazed treatment (Table 9), representing utilization of 246,635,000 cal/m$^2$. A major period of water loss on the ungrazed treatment occurred between July 9 to 22 when 94,840 g/m$^2$ were evaporated, indicating an energy utilization of 56,240,000 cal/m$^2$ or 4,017,400 cal/m$^2$/day.

It was assumed that precipitation on the grazed treatment was the same as on the ungrazed treatment. Evapotranspiration losses on the grazed treatment totaled 427.21 mm/cm$^2$ or 427,210 g/m$^2$, a total energy utilization of 253,336,000 cal/m$^2$. Energy utilized in evapotranspiration on the grazed treatment was thus about 3% greater than on the ungrazed treatment. Maximum evapotranspiration loss on the grazed treatment occurred during the period June 11 to 24, when losses totaled 115,680 g/m$^2$ over the 14-day period. This represented an average energy utilization of 4,899,850 cal/m$^2$/day.

Soil heat flux has been calculated by considering the water fractions and the mineral fractions of a soil column 1 $cm^2$ and 120 cm deep as separate entities, a procedure suggested by Munn (1966). Changes in heat balance in this postulated soil column were calculated from changes in average temperatures, and water content of the soil column with temperatures taken from the soil profile temperature values given in Tables 15 and 16 in Whitman (1971).

The data for the heat balance of the water fraction of the soil columns on the ungrazed and grazed treatments are given in Tables 11 and 12. The data of Table 11 show a net heat loss for the entire observation period for the water fraction on the ungrazed treatment of 409,000 cal/$m^2$. The grazed treatment shows an equivalent loss of 1,097,000 cal/$m^2$ for the same period (Table 12).

The data for the heat balance of the mineral fractions of the soil columns on the ungrazed and grazed treatments are given in Tables 13 and 14. In making these calculations a constant specific heat value of 0.25 cal/g of soil mineral material was used (Baver, 1956). The heat balance for the mineral fraction of the soil on the ungrazed treatment showed a positive balance of 2,433,000 cal/$m^2$ over the 155-day period of observation, while the mineral fraction heat balance on the grazed treatment showed a net loss of 1,728,000 cal/$m^2$ over the same period. The average temperature of the soil column on the grazed treatment was appreciably higher throughout the season than the average temperature of the soil column on the ungrazed treatment (Whitman, 1971).

The complete energy budgets for the ungrazed and grazed treatments are given in Tables 15 and 16. In these tables the net radiation values are

Table 11. Heat balance in water fraction of soil column[a/] on ungrazed treatment (1) at Dickinson Site, 1970 season.

| Period | No. of Days in Period | Approximate Average Soil Temperature Change (°C) | Average cal in Water Fraction of Soil Column at Start of Period | Average cal in Water Fraction at End of Period | Change in Heat Balance ($cal/cm^2$) | Change in Heat Balance ($cal/m^2 \times 1000$) |
|---|---|---|---|---|---|---|
| May 16 to May 25 | 10 | +2.5 | 154.2 | 210.6 | +56.4 | +564 |
| May 26 to June 10 | 16 | +2.6 | 210.6 | 287.8 | +77.2 | +772 |
| June 11 to June 24 | 14 | +1.6 | 287.8 | 315.3 | +27.5 | +275 |
| June 25 to July 8 | 14 | +2.3 | 315.3 | 287.8 | -28.0 | -280 |
| July 9 to July 22 | 14 | +1.5 | 287.3 | 190.3 | -97.3 | -973 |
| July 23 to August 4 | 13 | +0.6 | 190.3 | 252.6 | +62.3 | +623 |
| August 5 to August 18 | 14 | +0.3 | 252.6 | 229.8 | -22.8 | -228 |
| August 19 to September 17 | 30 | -1.7 | 229.8 | 134.6 | -95.2 | -952 |
| September 18 to October 17 | 30 | -4.4 | 134.6 | 113.6 | -21.0 | -210 |
| TOTALS | 155 | +5.3 | -- | -- | -40.9 | -409 |

a/ Soil column is 1 $cm^2$ in cross section and 120 cm deep.

Table 12. Heat balance in water fraction of soil column[a/] on grazed treatment (4) at Dickinson Site, 1970 season.

| Period | No. of Days in Period | Approximate Average Soil Temperature Change (°C) | Average cal in Water Fraction of Soil Column at Start of Period | Average cal in Water Fraction at End of Period | Change in Heat Balance ($cal/cm^2$) | Change in Heat Balance ($cal/m^2 \times 1000$) |
|---|---|---|---|---|---|---|
| May 16 to May 25 | 10 | +2.1 | 238.1 | 257.5 | +19.4 | +194 |
| May 26 to June 10 | 16 | +3.5 | 257.5 | 315.6 | +58.1 | +581 |
| June 11 to June 24 | 14 | +1.1 | 315.6 | 367.8 | +52.2 | +522 |
| June 25 to July 8 | 14 | +3.6 | 367.8 | 479.1 | +111.3 | +1,113 |
| July 9 to July 22 | 14 | +1.5 | 479.1 | 207.8 | -271.3 | -2,713 |
| July 23 to August 4 | 13 | -0.2 | 207.8 | 234.9 | + 27.1 | +271 |
| August 5 to August 18 | 14 | +0.6 | 234.9 | 236.0 | +1.1 | +11 |
| August 19 to September 17 | 30 | -2.6 | 236.0 | 156.3 | -79.7 | -797 |
| September 18 to October 17 | 30 | -5.7 | 156.3 | 128.4 | -27.9 | -279 |
| TOTALS | 155 | +3.9 | -- | -- | -109.7 | -1,097 |

a/ Soil column is 1 $cm^2$ in cross section and 120 cm deep.

Table 13. Heat balance in mineral fraction of soil column[a/] on ungrazed treatment (1) at Dickinson Site, 1970 season.

| Period | No. of Days in Period | Approximate Average Soil Temperature Change (°C) | Average cal in Mineral Fraction of Soil Column at Start of Period | Average cal in Mineral Fraction at End of Period | Change in Heat Balance ($cal/cm^2$) | Change Heat Balance ($cal/m^2 \times 1000$) |
|---|---|---|---|---|---|---|
| May 16 to May 25 | 10 | +2.5 | 269.7 | 378.9 | +109.2 | +1,092 |
| May 26 to June 10 | 16 | +2.6 | 378.9 | 488.6 | +109.7 | +1,097 |
| June 11 to June 24 | 14 | +1.6 | 488.6 | 560.1 | +71.5 | +715 |
| June 25 to July 8 | 14 | +2.3 | 560.1 | 658.8 | +98.7 | +987 |
| July 9 to July 22 | 14 | +1.5 | 658.8 | 724.3 | +65.5 | +655 |
| July 23 to August 4 | 13 | +0.6 | 724.3 | 751.0 | +26.7 | +267 |
| August 5 to August 18 | 14 | +0.3 | 751.0 | 763.6 | +12.6 | +126 |
| August 19 to September 17 | 30 | -1.7 | 763.6 | 697.4 | -66.2 | -662 |
| September 18 to October 17 | 30 | -4.4 | 697.4 | 513.0 | -184.4 | -1,844 |
| TOTALS | 155 | +5.3 | -- | -- | +243.3 | +2,433 |

a/ Soil column is 1 $cm^2$ in cross section and 120 cm deep.

Table 14. Heat balance in mineral fraction of soil column[a/] on grazed treatment (4) at Dickinson Site, 1970 season.

| Period | No. of Days in Period | Approximate Average Soil Temperature Change (°C) | Average cal in Mineral Fraction of Soil Column at Start of Period | Average cal in Mineral Fraction at End of Period | Change in Heat Balance ($cal/cm^2$) | Change in Heat Balance ($cal/m^2 \times 1000$) |
|---|---|---|---|---|---|---|
| May 16 to May 25 | 10 | +2.1 | 393.5 | 485.2 | +91.7 | +917 |
| May 26 to June 10 | 16 | +3.5 | 485.2 | 630.3 | +145.1 | +1,451 |
| June 11 to June 24 | 14 | +1.1 | 630.3 | 676.9 | +46.6 | +466 |
| June 25 to July 8 | 14 | +3.6 | 676.9 | 826.2 | +149.3 | +1,493 |
| July 9 to July 22 | 14 | +1.5 | 826.2 | 890.1 | +63.9 | +639 |
| July 23 to August 4 | 13 | -0.2 | 890.1 | 881.7 | -8.4 | -84 |
| August 5 to August 18 | 14 | +0.6 | 881.7 | 904.6 | +22.9 | +229 |
| August 19 to September 17 | 30 | -2.6 | 904.6 | 800.8 | -103.8 | -1,038 |
| September 18 to October 17 | 30 | -5.7 | 800.8 | 566.3 | -234.5 | -2,345 |
| TOTALS | 155 | +3.9 | -- | -- | -172.8 | -1,728 |

a/ Soil column is 1 $cm^2$ in cross section and 120 cm deep.

Table 15. Energy budget for the 155-day observation period on the ungrazed treatment (1) at the Dickinson Site, 1970 season.

| Period | No. of Days in Period | Net Radiation for period ($cal/m^2 \times 1000$) | Plant Production[a] for Period ($cal/m^2 \times 1000$) | Evapotranspiration for Period ($cal/m^2 \times 1000$) | Soil Heat Flux for Period ($cal/m^2 \times 1000$) | Ambient Air Heat Flux for Period ($cal/m^2 \times 1000$) |
|---|---|---|---|---|---|---|
| May 16 to May 25 | 10 | 24,051 | 165 | 2,876 | 1,656 | 19,354 |
| May 26 to June 10 | 16 | 66,511 | 282[b] | 20,559 | 1,869 | 43,801 |
| June 11 to June 24 | 14 | 56,578 | 2,719[b] | 32,722 | 990 | 20,147 |
| June 25 to July 8 | 14 | 68,806 | 222 | 35,722 | 707 | 32,155 |
| July 9 to July 22 | 14 | 62,553 | 239 | 56,240 | -318 | 6,392 |
| July 23 to August 4 | 13 | 48,644 | 180[b] | 23,839 | 890 | 23,735 |
| August 5 to August 18 | 14 | 56,901 | 341[b] | 40,763 | -102 | 15,899 |
| August 19 to September 17 | 30 | 75,922 | 864[b] | 21,301 | -1,614 | 55,371 |
| September 18 to October 17 | 30 | 25,800 | 36 | 12,613 | -2,054 | 15,205 |
| TOTALS | 155 | 485,766 | 5,048 | 246,635 | 2,024 | 232,059 |

a/ Based on positive increments of community production.

b/ Increment of root production added to aboveground production.

Table 16. Energy budget for the 155-day observation period on the grazed treatment (4) at the Dickinson Site, 1970 season.

| Period | No. of Days in Period | Net Radiation for Period ($cal/m^2 \times 1000$) | Plant Production[a] for Period ($cal/m^2 \times 1000$) | Evapotranspiration for Period ($cal/m^2 \times 1000$) | Soil Heat Flux for Period ($cal/m^2 \times 1000$) | Ambient Air Heat Flux for Period ($cal/m^2 \times 1000$) |
|---|---|---|---|---|---|---|
| May 16 to May 25 | 10 | 23,943 | 215 | 36,914 | 1,111 | -14,297 |
| May 26 to June 10 | 16 | 61,235 | 240 | 6,565 | 2,032 | 52,398 |
| June 11 to June 24 | 14 | 52,999 | 2,348[b] | 68,598 | 988 | -18,935 |
| June 25 to July 8 | 14 | 63,310 | 137 | 20,838 | 2,606 | 39,729 |
| July 9 to July 22 | 14 | 56,160 | 107 | 34,240 | -2,074 | 23,887 |
| July 23 to August 4 | 13 | 45,198 | 93 | 30,658 | 187 | 14,260 |
| August 5 to August 18 | 14 | 52,206 | 121 | 18,822 | 240 | 33,023 |
| August 19 to September 17 | 30 | 65,564 | 139 | 23,495 | -1,835 | 43,765 |
| September 18 to October 17 | 30 | 19,441 | 50 | 13,206 | -2,624 | 8,809 |
| TOTALS | 155 | 440,056 | 3,450 | 253,336 | 631 | 182,639 |

a/ Based on positive increments of community production.

b/ Increment of root production added to aboveground production.

taken from the measured values as given in Whitman (1971, Tables 17 and 18). Plant production values were calculated from the positive increments of aboveground standing crop production plus the positive increments of belowground biomass production. Evapotranspiration data are from the water balance calculations given in Tables 9 and 10. Soil heat flux data have been obtained from the algebraic summing of heat flux data for the water fractions and the mineral fractions of the soil columns as given in Tables 11, 12, 13, and 14.

The data show that over the 155-day period total energy absorbed on the ungrazed treatment was 10.4% greater than on the grazed treatment. Most of the additional energy absorbed went to heating the ambient air, although a small fraction of it went into plant production and into stored soil heat. On the grazed treatment energy utilized in evapotranspiration was slightly greater than on the ungrazed site. In the early part of the season evapotranspiration demands on the grazed treatment actually resulted in part of the energy for this operation being derived from the ambient air. On the ungrazed treatment there is no indication that advected heat from the air was used in the energetics of the system.

By far the largest utilization of energy on the two treatments was in evapotranspiration and in the heating of the ambient air. On a percentage basis the following utilization of net radiation occurred on the ungrazed treatment over the observation period: plant production (1.04%), evapotranspiration (50.77%), soil heat flux (0.42%), and sensible heat (47.77%). On the grazed treatment equivalent values were plant production (0.79%), evapotranspiration (57.57%), soil heat flux (0.14%), and sensible heat (41.50%).

Certain aspects of the energy budget on the grazed treatment are especially interesting in attempting to determine whether important differences between the energy budgets on the ungrazed and grazed treatments do exist. Total net radiation was less on the grazed treatment than on the ungrazed treatment (Tables 15 and 16). The question could be raised as to whether this is a real difference. The basic net radiation data were examined in some detail, and it was found that reradiation from the grazed treatment was greater at night than from the ungrazed treatment. The assumption would logically be that reradiation was also greater during the day, although there is no way to verify this from the data available from the site. The evidence, while not positive, does seem to suggest that the grazed treatment lost more heat by reradiation than did the ungrazed treatment, which would account for the lower net radiation values on this treatment.

The energy losses in evapotranspiration on the grazed treatment in the early part of the season were much greater than the losses on the ungrazed treatment. From the data given in Table 16 it would appear that in the May 16 to 25 and June 11 to 24 periods the energy requirements for evapotranspiration were greater than the total net radiation and that advected heat from the ambient air was necessary to provide the energy needed. The question could be raised as to whether this situation was real, or whether it resulted from errors in soil water determinations. The use of advected heat to provide energy for evapotranspiration losses has been noted before on the site, and it seems probable that the picture of evapotranspiration energy requirements on the grazed treatment is reasonably realistic. However, the possibility of error cannot be ruled out. Fortunately, the data from the 1971 season, taken under an essentially similar situation, may be useful in clarifying this picture. The data from this past season's study are only now being assembled and will not be available until early in 1971.

OTHER DATA

Relative humidity data taken during the 1970 season at 15 cm above the soil surface and 1 m above canopy height on both the ungrazed and grazed treatments are on file at the Botany Department, North Dakota State University. From these data vapor pressure deficits have been calculated, and these also are on file. These data will be provided on request to anyone who may have an interest in them.

Total incoming radiation data (Eppley pyrheliometer) are taken as a matter of routine at the Dickinson Site. Unfortunately, during the 1970 growing season faulty operation of the recorder resulted in only a fragmentary record being obtained. The record, such as it is, can be made available.

The 1971 abiotic data and the primary productivity data from the Dickinson Site should be summarized by April of 1972. These data will be supplied to Grassland Biome cooperators on request.

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# APPENDIX I

## APPENDIX TABLES

Appendix Table 1.[a/] Herbage dynamics ($g/m^2$) on the ungrazed treatment (1) at the Dickinson Site, 1970 season.

| Species | Sampling Dates | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | May 25 | June 10 | June 24 | July 8 | July 22 | Aug. 4 | Aug. 18 | Sept. 17 | Oct. 17 |
| | | | | *Grasses* | | | | | |
| *Agropyron smithii* | 4.0 | 7.4 | 26.5 | 23.9 | 29.0 | 27.2 | 33.8 | 34.6 | 12.9 |
| *Bouteloua gracilis* | 1.2 | 4.8 | 10.4 | 19.4 | 25.9 | 20.4 | 28.9 | 29.8 | 25.0 |
| *Calamovilfa longifolia* | -- | 3.3 | 7.8 | 8.8 | 9.9 | -- | 16.6 | 30.0 | 20.0 |
| *Carex eleocharis* | 1.7 | 7.5 | 7.5 | 11.3 | 8.4 | 12.2 | 10.3 | 9.1 | 16.4 |
| *Stipa comata* | 26.2 | 33.8 | 49.6 | 77.4 | 100.8 | 118.3 | 105.1 | 105.5 | 103.7 |
| Miscellaneous grasses | -- | -- | 5.8 | 3.1 | 0.3 | 0.4 | 3.3 | 4.4 | 5.2 |
| | | | | *Forbs* | | | | | |
| *Artemisia ludoviciana* | 2.6 | 11.9 | 18.7 | 19.9 | 37.7 | 36.3 | 42.6 | 83.0 | 52.9 |
| Annual forbs | -- | 0.1 | 0.9 | 4.8 | 0.2 | 0.5 | 0.7 | 1.3 | 0.9 |
| Biennial forbs | 0.5 | 1.1 | 12.8 | 8.0 | 5.2 | 8.2 | 4.3 | 1.0 | 3.5 |
| Other perennial forbs | 1.0 | 3.3 | 14.9 | 22.3 | 5.5 | 21.4 | 6.3 | 21.2 | 2.0 |
| TOTAL standing crop | 37.2 | 73.2 | 154.9 | 198.9 | 222.9 | 244.9 | 251.9 | 319.9 | 242.5 |
| Standing dead (previous year's) | 331.3 | 383.2 | 345.5 | 276.1 | 333.8 | 331.0 | 271.8 | 352.5 | 286.0 |
| Litter | 796.7 | 604.2 | 538.3 | 523.4 | 626.8 | 624.9 | 661.5 | 607.0 | 648.8 |
| TOTAL biomass | 1165.2 | 1060.6 | 1038.7 | 998.4 | 1183.5 | 1200.8 | 1185.2 | 1279.4 | 1177.3 |
| *Selaginella densa* | 3.0 | -- | 1.1 | 1.4 | -- | 0.8 | 0.2 | 0.2 | -- |
| TOTAL with *Selaginella* | 1168.2 | 1060.6 | 1039.8 | 999.8 | 1183.5 | 1201.6 | 1185.4 | 1279.6 | 1177.3 |

a/ Basic data from Whitman (1971; Table 27).

Appendix Table 2.[a] Herbage dynamics ($g/m^2$) on the grazed treatment (4) at the Dickinson Site, 1970 season.

| Species | Sampling Dates | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | May 25 | June 10 | June 24 | July 8 | July 22 | Aug. 4 | Aug. 18 | Sept. 17 | Oct. 17 |
| | | | | *Grasses* | | | | | |
| *Agropyron smithii* | -- | 5.5 | 6.2 | 10.6 | 11.7 | 7.9 | 19.8 | 16.3 | 11.1 |
| *Bouteloua gracilis* | 4.2 | 18.3 | 42.0 | 37.8 | 50.6 | 46.1 | 59.9 | 56.0 | 59.9 |
| *Calamagrostis montanesis* | 21.5 | 19.1 | 23.4 | 26.6 | 27.1 | 19.9 | 15.3 | 20.6 | 22.3 |
| *Carex eleocharis* | 4.6 | 6.8 | 16.9 | 13.7 | 13.8 | 11.0 | 11.5 | 8.1 | 7.5 |
| *Koeleria cristata* | 5.5 | 12.3 | 6.4 | 18.0 | 13.3 | 18.5 | 16.8 | 10.3 | 15.9 |
| *Stipa comata* | 8.3 | 24.0 | 30.1 | 35.0 | 42.1 | 56.1 | 45.0 | 47.9 | 46.9 |
| Miscellaneous grasses | -- | 1.5 | 0.9 | 0.1 | 1.1 | 0.2 | 0.4 | -- | -- |
| | | | | *Forbs* | | | | | |
| *Artemisia ludoviciana* | -- | -- | -- | 3.0 | 1.6 | 3.4 | 4.2 | 5.2 | -- |
| Annual forbs | -- | 1.4 | 5.9 | 5.0 | 4.1 | 3.4 | 5.0 | 12.3 | 2.1 |
| Biennial forbs | -- | -- | -- | -- | -- | 0.1 | 0.2 | -- | 0.2 |
| Other perennial forbs | 4.3 | 11.1 | 16.9 | 21.6 | 24.0 | 21.8 | 18.3 | 33.2 | 20.8 |
| TOTAL standing crop | 48.4 | 100.0 | 148.7 | 171.4 | 189.4 | 188.4 | 196.4 | 209.9 | 186.7 |
| Standing dead (previous year's) | 17.4 | 18.7 | 26.3 | 29.3 | 58.2 | 49.8 | 35.6 | 24.9 | 17.8 |
| Litter | 94.8 | 87.2 | 91.1 | 100.2 | 169.4 | 202.4 | 209.3 | 198.7 | 205.7 |
| TOTAL biomass | 160.6 | 205.9 | 266.1 | 300.9 | 417.0 | 440.6 | 441.3 | 433.5 | 410.2 |
| *Selaginella densa* | 43.6 | 30.6 | 54.3 | 42.4 | 35.6 | 45.1 | 25.9 | 47.6 | 70.8 |
| TOTAL with *Selaginella* | 204.2 | 236.5 | 320.4 | 343.3 | 452.6 | 485.7 | 467.2 | 481.1 | 481.0 |

[a] Basic data from Whitman (1971; Table 28).

Appendix Table 3. Caloric content of aboveground organic material in calories per gram ash-free dry weight and percent ash.[a/]

| Organic Material | May 17 | June 5 | June 16 | June 30 | July 14 | July 28 | Aug. 8 | Aug. 25 | Ash (%) |
|---|---|---|---|---|---|---|---|---|---|
| *Agropyron smithii* | 4454 | 4492 | 4604 | 4586 | 4306 | 4325 | 4147 | 4090 | 7.5 |
| *Bouteloua gracilis* | 4426 | 4249 | 4015 | 4554 | 4445 | 4374 | 4128 | 4378 | 7.5 |
| Forbs | 4404 | 4148 | 4404 | 4525 | 4796 | 4461 | 4658 | 4606 | 8.4 |
| Litter | 4035 | 4036 | 4112 | 3584 | 3940 | 3824 | 3405 | 3940 | 37.2 |
| *Selaginella densa* | -- | 4484 | 4208 | 4117 | 3696 | 3997 | 4471 | 4139 | 37.2 |
| Standing dead | 3860 | 4477 | 4471 | 4145 | 4212 | 4224 | 4535 | 3925 | 17.6 |
| *Stipa comata* | 4508 | 4671 | 4565 | 4699 | 4733 | 4115 | 4678 | 4543 | 6.8 |

[a/] Caloric contents are from single determinations and percent ash was determined for duplicate samples.

Appendix Table 4. Caloric content of root mass in calories per gram ash-free dry weight and percent ash.[a/]

| Depth (cm) | June 11 | June 24 | July 10 | July 22 | Aug. 8 | Aug. 25 | Ash (%) |
|---|---|---|---|---|---|---|---|
| 0 to 15 | 3830 | 3944 | 3511 | 3751 | 4032 | 3853 | 45.5 |
| 15 to 30 | 3270 | 4457 | 2731 | 4106 | 4157 | 3621 | 51.4 |
| 30 to 45 | 3678 | 4139 | 2813 | 3322 | 3686 | 3579 | 50.5 |
| 45 to 60 | 2926 | 3823 | 2375 | 2741 | 3207 | 3347 | 50.5 |
| 60 to 90 | 2841 | 4248 | 2051 | 3074 | 3790 | 3266 | 54.3 |

[a/] Caloric contents are from single determinations and percent ash was determined for duplicate samples.